

CONTAMINATION AND PROTECTION OF GROUND WATERS IN THE ALLUVIAL SEDIMENTS OF THE BREGALNICA RIVER IN THE DELČEVO REGION, DEPENDING ON THEIR HYDROGEOLOGICAL CHARACTERISTICS

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Abstract: The alluvial sediments in the Delčevo region are a two layer porous environment built of different granulometric and filtration characteristics. The lower layer is a coarse porous water-bearing environment present as a gravel sandy series ($K = 96 - 276$ m/day) and finer-grained granulometric sands with clay interlayers the filtration coefficient being $K = 1.73 \cdot 10^{-2} - 17.28$ m/day, underlying a layer of rather weaker filtration characteristics made up of sandy clays ($K = 2.16 \cdot 10^{-3}$ m/day), and dusty sands the filtration coefficient being $K = 3.15 \cdot 10^{-2}$ m/day. The lithological-hydrogeological characteristics of the cover sediments do not provide sufficient protection of ground waters against contamination of the Bregalnica alluvion in the Delčevo region and pertain to the waters endangered from contamination.

Key words: ground waters; contamination; protection; cover sediments; alluvial sediments; Bregalnica; Delčevo

INTRODUCTION

The issue of environmental pollution, particularly surface and ground waters has been subject matter of concern over the past decades as a result of industrial development and the use of chemical in agriculture.

The alluvial sediments of the Bregalnica River in the Delčevo region are widespread occurring

in an elongated belt from Trabotivište to Oči Pale, south of Delčevo on both sides of the river as river terraces. The sediments contain significant amounts of ground waters that are used for water supply of a number of industrial facilities or houses from excavation wells. Present day life style results in anthropogenic pollution.

GEOLOGICAL COMPOSITION OF THE WIDER AREA

The Delčevo area is composed of Cambrian, Paleozoic, Triassic, Paleogene, Neogene and Quaternary rocks (Ковачевиќ et al., 1973).

The oldest rocks are the Cambrian amphibole gabbros occurring as large or small masses with sharp margins towards the Paleozoic granites and greenschists.

The Paleozoic rocks are present as graphite-quartz schists phyllites and quartz-sericite schists, granodiorites, quartzdiorites, schistose biotite

coarse-grained granites (occupying a large area of the Delčevo area) as well as Permian grey clayey sandstones.

The Triassic rocks are present as sandstones, sandy clays and conglomerates, layered and milonitized limestones occurring in a small area.

The Paleogene is present as Eocene conglomerates, sandstones, slates, marls and quartzlatite volcanic intrusions.

The Neogene is present as Pliocene sediments as a clay facies, loams and sands that comprise the

lower parts of the Pliocene as well as a gravel and sand facies comprising the upper parts.

The youngest rocks are those of the Quaternary present as proluvial and alluvial sediments extending mostly along the Bregalnica River.

HYDROGEOLOGICAL CHARACTERISTICS OF THE WIDER AREA

The structural type of porosity in the wider surrounding in Delčevo made it possible to distinguish

Boundary type of aquifer,
Fracture type of aquifer,

Karst type of aquifers, and
Conditionally waterless terrains.

A characteristic hydrogeological cross-section for the area under investigations is shown in Fig. 1.

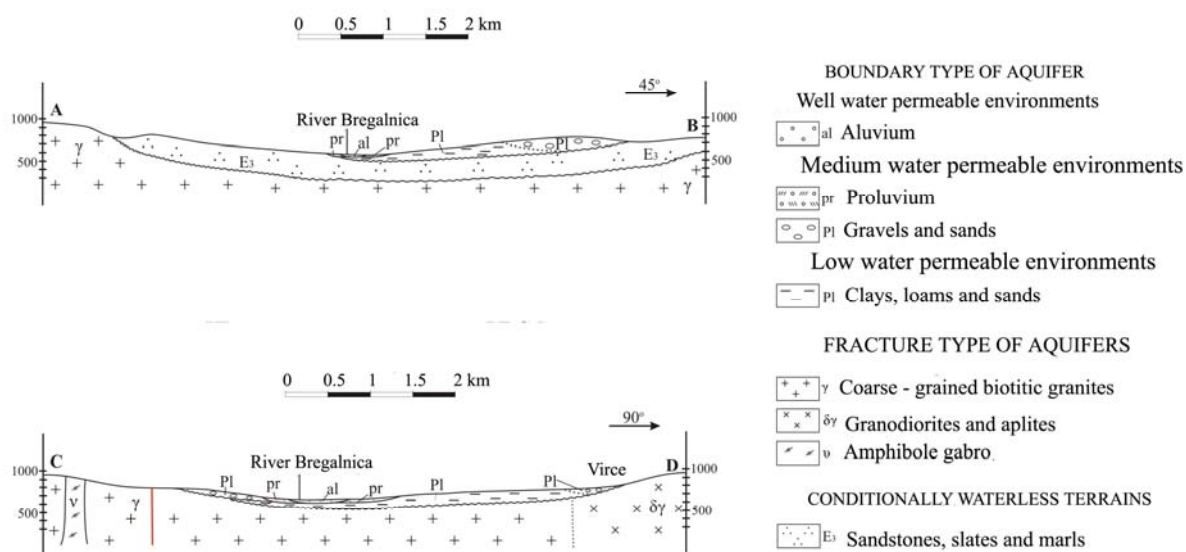


Fig. 1. Hydrogeological cross-section of the area under investigations

Boundary type of aquifers occurs in alluvial and proluvial sediments and in the Pliocene gravels, sands, clays and loams.

Based on water permeability boundary type of aquifers have been divided into

- *well water permeable environments*,
- *medium water permeable environments*, and
- *low water permeable environments*.

Well water permeable environments are made up of alluvial sediments located close to the Bregalnica River and the smaller river flows in the region.

Medium water permeable environments occupy a large area in the right side of the Bregalnica River. They are present as Pliocene sands, gravels and proluvial sediments.

Low water permeable environments are situated in the right side of the Bregalnica present as Pliocene, clays, loams and sands.

The fracture type of aquifers formed in the hard rock masses as quartzlatites, sandstones, sandy clays and conglomerates, grey clayey sandstones, schistose biotite coarse-grained granites, quartzdiorites, granodiorites, aplites, phyllites, quartz-sericite schists, graphite-quartz schists and amphibole gabbros.

The karst type of aquifers occurs in a small area in the Triassic limestones that are characterized with cavernous porosity.

Conditionally waterless terrains are made up of Eocene conglomerates, sandstones, slates and marls

STRUCTURAL-LITHOLOGICAL CHARACTERISTICS OF THE ALLUVIAL SEDIMENTS

The alluvial sediments in the region of Delčevo are located mostly along the valley of the Bregalnica, and less along other river flows. Along the Bregalnica they occur as an elongated belt on a 16 km long strike from Trabatovište to the Oči Pale locality, south of Delčevo. They occur as 100 to 600 meters wide river terraces on both sides of the river.

In the area, the alluvial sediments are a distinct geological and hydrogeological unit separated from the Pliocene and Eocene sediments in which significant amounts of ground waters have been accumulated as boundary type of aquifers.

The structural-lithological characteristics of the alluvial sediments in the Delčevo region were

discovered with the hydrogeological investigations carried out for the water supply (Максимов and Ивановски, 2004) and the uncovered cross-sections close to the Bregalnica.

Hydrogeological investigations discovered the structural location of the alluvial sediments relative to the basal Pliocene sediments as well as their fa- cial lithological changes.

A characteristic geological-hydrogeological cross-section revealed during drilling a drill-hole is shown in Fig. 2. The drill-hole is in the first river terrace of the Bregalnica, 100 meters from the river-bed close to the leather factory in the industrial sector of the town.

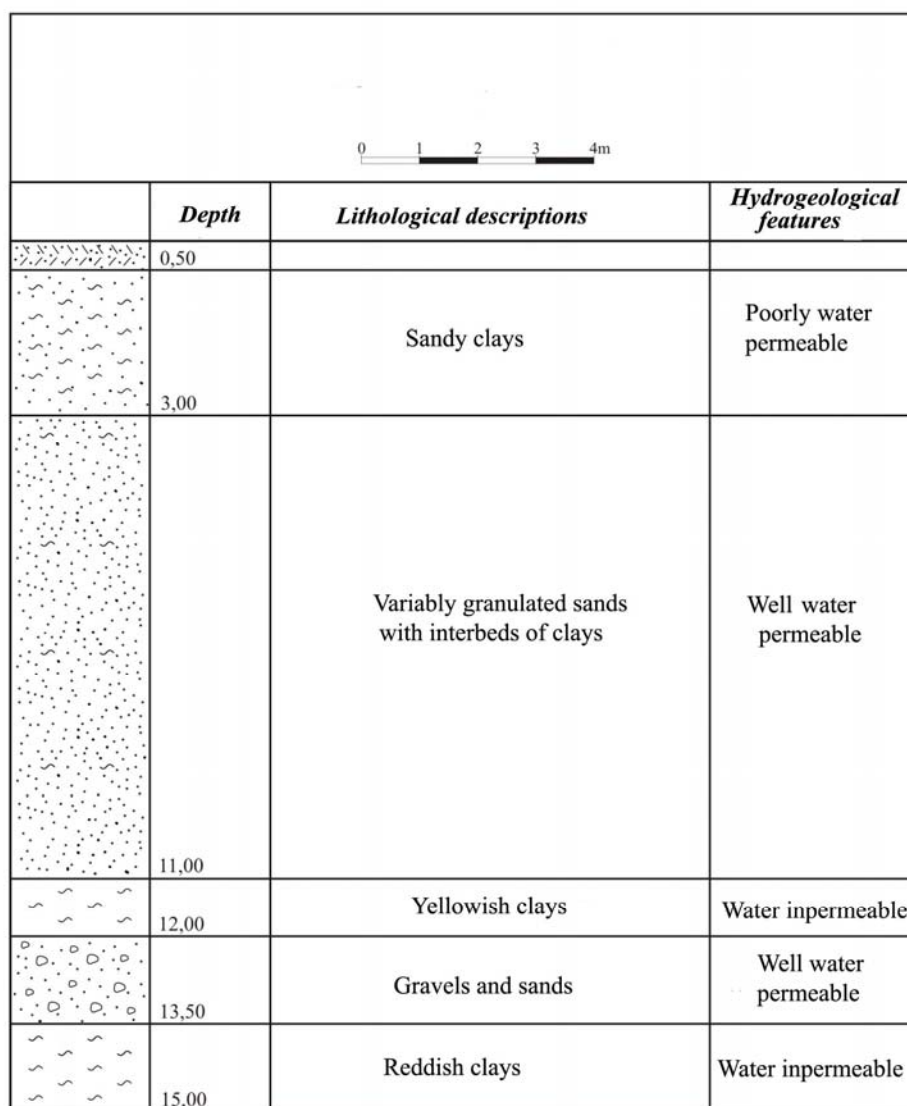


Fig. 2. Geological-hydrogeological cross-section of a drill-hole drilled in alluvial sediments

Based on this drill-hole the base of the alluvial sediments is 13.5 meters in depth. Larger porous gravels and sands have accumulated above the Pliocene clays. Clayey sediments alternate finer-grained variably granulated sands with interbeds of clays, sandy clays towards the surface. In the end the cross-section ends in dust-sandy sediments.

The lithological-hydrogeological characteristics of the alluvial sediments can be seen from the cross-sections near the Bregalnica.

Fig. 3 shows a cross-section of alluvial sediments close to the Golak dairy farm 4 km north-

west of Delčevo. The cross-section is some 20 meters from the Bregalnica river-bed, formed with gravel and sand diggings. The cross-section is about 2.5 meters deep, the level of the ground water being 2 meters in depth. Two lithological units can clearly be distinguished in the cross-section: a cover made up of 40 to 50 cm dusty sands overlying alluvial sediments made up of gravel and sand whose thickness has not been determined and can not be assessed.

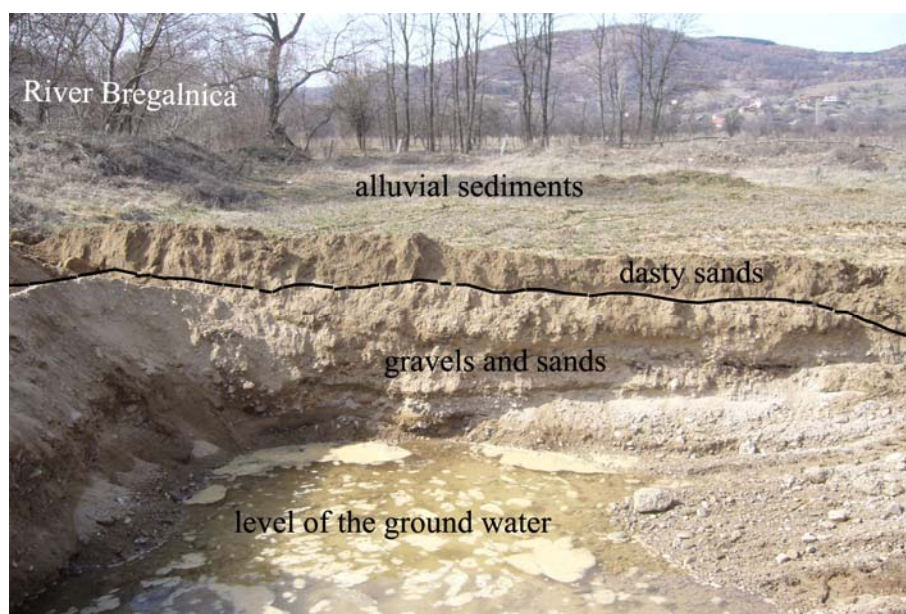


Fig. 3. Cross-section of alluvial sediments near the Bregalnica River, close to the Golak dairy farm 4 km north-west from Delčevo

A well discovered cross-section of alluvial sediments can be seen 6 km south-east from Delčevo, in close proximity to the Bregalnica near the pig farm (Fig. 4). In both cross-sections alluvial sediments and the cover layer can be seen clearly. The cover layer is 40 to 50 cm thick being made up of dusty sands. Right below the cover layer are the alluvial sediments present as coarse- to medium-size gravels and sands. The height of the alluvial terrace in this part amounts from 2.5 to 3 meters above the Bregalnica River level.

A well has been drilled in the Bregalnica River alluvion for the water supply of the Granite Construction Company Base when entering Delčevo from Berovo. An 8 to 9 meters thick alluvial water-bearing layer has been determined made up of gravels and sands (Ѓузелковски, 1997).

Based on the data presented so far it can be said that the alluvial sediments in the Delčevo region transgressively and discordantly overlie the

Pliocene sediments made up of clays, loams and sands.

A gravel sandy series and a series of with sands with clay interbeds can be distinguished with accumulated over sediments made up of sandy clays and dusty sands.

The thickness of alluvial sediments varies from 5 to 15 meters being the thickest close to the Bregalnica, getting thinner going further from the river.

Investigations carried out so far have determined that the thickness of the gravel-sandy series amounts to 9 meters, and that of the cover sediments from 0.4 to 4 meters.

The thickness of the cover sediments is smallest close to the river amounting from 0.4 to 0.5 meters and increases going further from the river-bed on the left and the right sides being 4 meters thick in some parts.

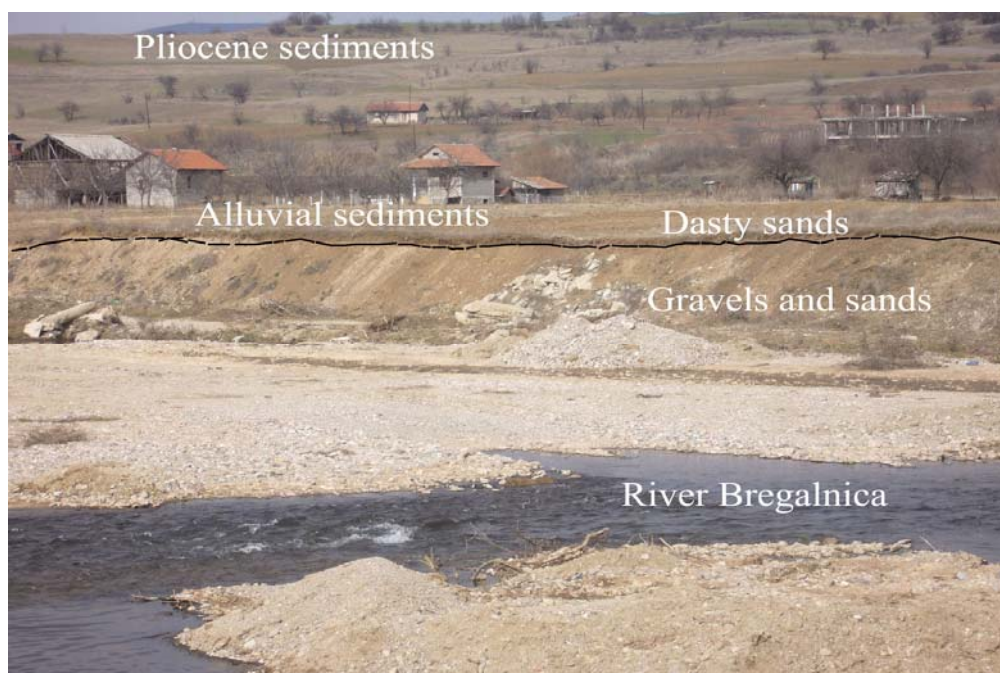


Fig. 4. Cross-section of alluvial sediments near the Bregalnica River, close to the pig farm 6 km south-east of Delčevo

GRANULOMETRIC COMPOSITION AND FILTRATION FEATURES OF THE LITHOLOGICAL MEMBERS

The base of the alluvial sediments is built of a series of gravels and sands and various granule sands with clay interbeds of supercapilar intergranular porosity creating a coarse porous environment. This coarse porous environment transgressively and discordantly is overlain by settled sediments of sandy clays and dusty sands of fine porosity. It is characteristic for both zones that they are horizontally spread in a large area with identical lithological and granulometric composition, whereas vertically they largely vary as is the case with the 0.4 to 4 meters thick cover sediments.

The filtration features of the cover sediments that are important for the protection of ground waters against contamination have been determined based on granulometric analyses. Samples were collected from uncovered cross sections shown in Figs 3 and 4 according to furrow method up to 0.5 meters in depth. Determination of filtration coefficient (K) was done according to USBR and Slichter methods in the Institute for Civil Engineering, Skopje. The results obtained have been given in Table 1.

Data obtained by both methods made it possible to calculate the mean filtration coefficient of cover sediments made up of dusty sands that amounts to $K = 3.15 \cdot 10^{-2}$ m/day.

From the results obtained it can be said that the cover sediments are of low to very low permeability.

The thickness of cover sediments that amounts to 0.4 to 0.5 meters for the areas near the river banks helped calculate the transmission coefficient or water permeability of the cover. If the mean thickness of the cover layer at the river bank amounts to 0.45 meters, transmissivity coefficient will amount to $T = 1.42 \cdot 10^{-2}$ m²/day.

Table 1

Values of filtration coefficient (K) according to the USBR and Slichter methods

	d_{10} (mm)	d_{20} (mm)	USBR (m/day)	Slichter (m/day)	Mean value for K (m/day)
Sample 1	0.003	0.008	$4.12 \cdot 10^{-3}$	$6.38 \cdot 10^{-4}$	$2.38 \cdot 10^{-3}$
Sample 2	0.008	0.018	$3.14 \cdot 10^{-2}$	$5.46 \cdot 10^{-4}$	$1.60 \cdot 10^{-2}$
Sample 3	0.007	0.02	$3.54 \cdot 10^{-2}$	$4.76 \cdot 10^{-3}$	$2.01 \cdot 10^{-2}$
Sample 4	0.012	0.04	$1.87 \cdot 10^{-1}$	$1.41 \cdot 10^{-3}$	$9.42 \cdot 10^{-2}$
Sample 5	0.009	0.02	$4.21 \cdot 10^{-2}$	$7.84 \cdot 10^{-3}$	$2.48 \cdot 10^{-2}$
					$3.15 \cdot 10^{-2}$

The filtration coefficient for the water-bearing gravel sandy series was determined based on data obtained with well testing drilled for water supply. According to this data the filtration coefficient is in the span of $K = 96 - 276$ m/day. The filtration coefficient for the finer-grained variably granulated sands with interbeds of clays according to Domenico & Schwartz (1990) is $K = 1.73 \cdot 10^{-2} - 17.28$ m/day.

Based on studies carried out it can be said that the alluvial sediments in the Delčevo region are two layer porous environment built of two layers of different granulometric and filtration characteristics.

The lower part is a coarse porous water-bearing environment with good filtration features overlain by a cover layer of significantly lower filtration features.

In order to understand the level of protection against contamination of the cover sediments of ground waters accumulated in the alluvial sediments it is necessary to assess the percolating speed of possible contaminants from the surface through the cover layer to the gravel sandy water-bearing layer as well as the time necessary for contamination through the cover layer to reach ground waters.

Since two cover layers have been found with different lithological composition and filtration features, the above parameters will be calculated for each layer individually.

Percolating speed through cover sediments can be determined by the equation

$$V_z = -\frac{K}{n_{ef}}i$$

V_z – percolating speed (m/day),

K – vertical filtration coefficient (m/day),

i – hydraulic gradient,

n_{ef} – effective porosity.

The vertical movement of liquid particles can, in the least possible case, approximate with the flow through empty cover semi porous layer of hydraulic gradient 1. According to the formula above the percolating speed through the cover layer made up of dusty sands amounts to $V_z = 7.87 \cdot 10^{-2}$ m/day; $K = 3.15 \cdot 10^{-2}$ m/day; $n_{ef} = 0.4$ mean value of fine-grained sand and dust according to Domenico & Schwartz (1998).

Percolating time through the cover layer to the water-bearing gravels and sands can be calculated by the formula $t = \frac{m}{V_z}$ amounting to 5.72

days,

t – time in days,

m – thickness of low permeable cover layer = 0.45 meters,

V_z – percolating speed = $7.87 \cdot 10^{-2}$ m/day.

Possible contamination will pass through the cover layer in 5.72 days which indicates that the dusty sands of the cover sediments near the river banks provide little protection to the ground waters accumulated in the water-bearing layer.

The following results have been obtained for the sandy clays of the cover sediments above the water-bearing layers made up of sands and clay interbeds, gravels and sands in the parts far from the river beds: filtration coefficient according to Domenico & Schwartz (1990). $K = 2.16 \cdot 10^{-3}$ m/day; coefficient of effective porosity according to Domenico & Schwartz (1998), $n_{ef} = 0.4$.

The value for percolating speed obtained amounts to $V_z = 5.4 \cdot 10^{-3}$ m/day. In 4 meter thick sediments contamination will pass in a time period of 185 days.

This fact points out that the cover sediments are a better protection relative to ground waters near the river banks.

GROUND WATERS FORMING IN THE ALLUVIAL SEDIMENTS

The geological and hydrogeological structural location of the alluvial sediments in the Delčevo area made possible the accumulation of significant amounts of ground waters. Ground waters have accumulated in a boundary type of water bearers in the alluvial layers made up of gravels and sands with clay interbeds. The water-bearing layer per-

tains to the open to semiclosed water-bearing layers or hydrogeological structures.

Recharge of the water-bearer with water is done mostly by the Bregalnica River waters, water falls, and waters from water flows in higher hypsometric level.

The general strike of ground water flow is towards and parallel to the Bregalnica River bed.

CONTAMINANTS OF GROUND WATERS IN THE ALLUVIAL SEDIMENTS OF THE BREGALNICA RIVER

The biggest active and possible contaminants of ground waters in the alluvial sediments of the Bregalnica in the Delčevo area are: the waters of the river, agricultural cultivable areas, animal farms, industrial facilities, landfills, waste waters discharged from settlements, petrol stations and

oils depots, regional and local roads and cemeteries. The location of contaminants is given in the map in Fig. 5.

The map clearly shows that most of the contaminants are near the Bregalnica River, on the alluvial terraces or in their immediate surrounding.

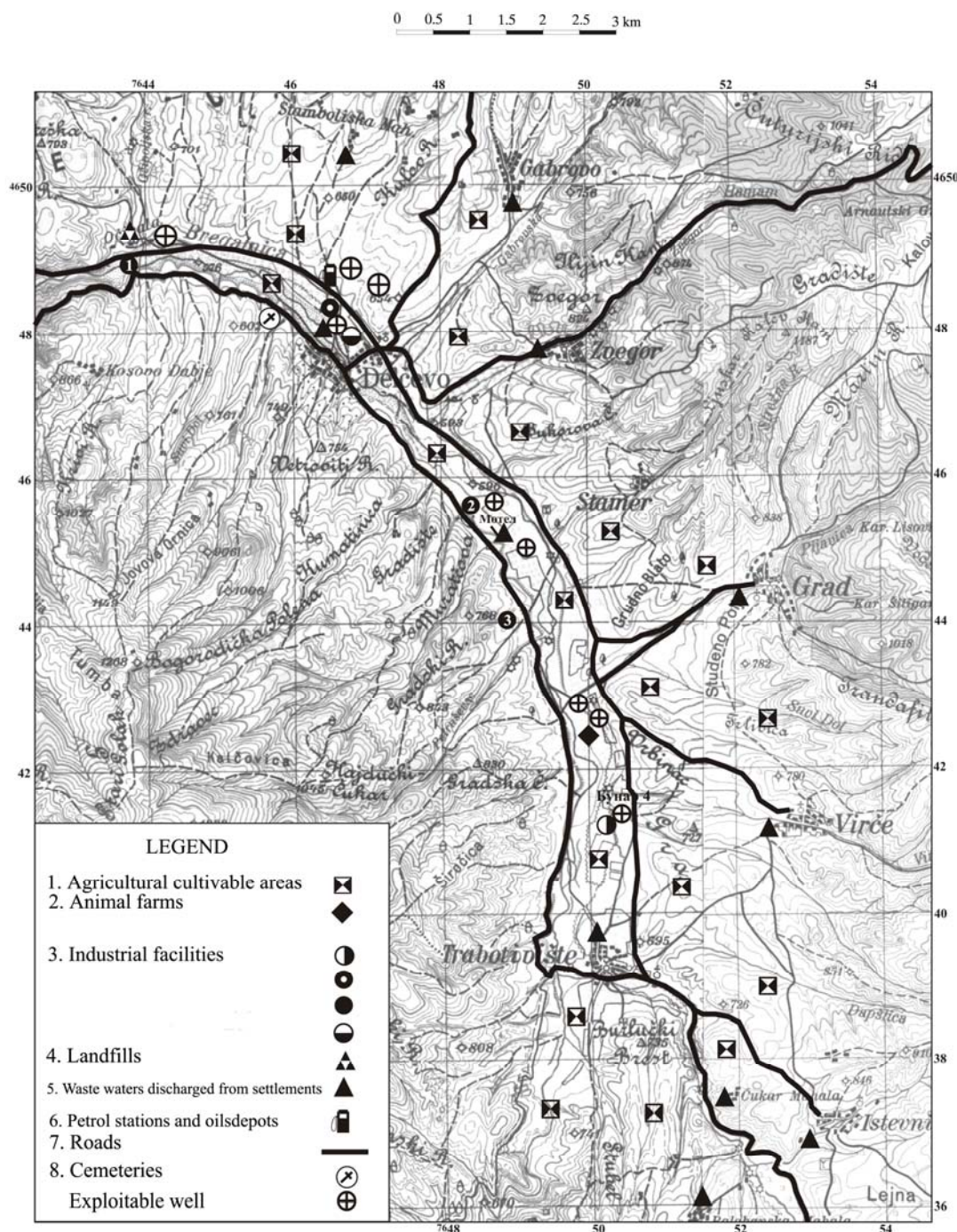


Fig. 5. Map of surface and ground waters contaminants of the wider vicinity of Delčevo

Waste from all contaminants, without any filtering or purification, directly or via discharge pipes flow into the Bregalnica River waters, in some cases into underground of the geological environment and further on into ground waters.

Based on the hydrogeological characteristics of the alluvial sediments and the location of the

bigger contaminants it can be said that the ground waters in the alluvial sediments in the Delčevo area are ground waters endangered from contamination. This means that the production of contaminating materials in the area endanger ground waters in the alluvial sediments.

MEASURES FOR THE PROTECTION OF GROUND WATERS IN ALLUVIAL SEDIMENTS

The protection of the natural quality of ground waters in the alluvial sediments along the Bregalnica River in the Delčevo area call for undertaking the activities as follows:

- waste waters discharged from the town of Delčevo and the bigger settlements must join a sewer system and purified before discharge into the Bregalnica,
- waste waters from industrial facilities and animal farms must join a sewer system and be purified before discharge into the river,
- the landfill and industrial waste from Delčevo and the bigger settlements must be dumped in the right constructed waste dump,

– to construct protection zones round the structures that supply drinking water for the population (well, water captures etc.),

– to compile a detailed inventory of pollutants and their impact on the environment,

– in the future, the vulnerability map of ground waters must be taken in consideration when constructing facilities that may endanger the environment. The map is part of the hydrogeological map of the Republic of Macedonia the scale 1 : 100 000,

– to compile a pisiometric net and measure points for the monitoring of surface and ground waters quality.

CONCLUSION

Water-bearing layers made up of gravel with sand and sands with clay interbeds in the basement with cover sediments accumulated above them (made up of sandy clays and dusty sands) have been distinguished in the alluvial sediments along the Bregalnica River.

The thickness and filtration characteristics of the cover sediments do not provide sufficient pro-

tection to ground waters accumulated in them against contamination coming from the area. In that regard, it can be said that the ground waters in the alluvial sediments in the Delčevo area belong to the endangered ground waters by contamination.

In order to protect the natural quality of ground waters it is necessary to undertake adequate preventive measures.

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Резиме

ЗАГАДУВАЊЕ И ЗАШТИТА НА ПОДЗЕМНИТЕ ВОДИ ВО АЛУВИЈАЛНИТЕ СЕДИМЕНТИ НА РЕКАТА БРЕГАЛНИЦА ВО РЕГИОНОТ НА ДЕЛЧЕВО, ВО ЗАВИСНОСТ ОД НИВНИТЕ ХИДРОГЕОЛОШКИ КАРАКТЕРИСТИКИ**Војо Мирчовски¹, Орце Спасовски¹, Владо Мирчовски²**¹Универзитет „Гоце Делчев“, Факултет за природни и технички науки,

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Клучни зборови: подземни воид; загадување; заштита; покривни седименти; алувијални седименти; Брегалница; Делчево

Алувијалните седименти од регионот на Делчево претставуваат двослојна порозна средина изградена од два слоја со различни гранулометриски и филтрациони карактеристики.

Долниот слој претставува грубо порозна водоносна средина претставена со чакалесто песклива серија ($K = 96 - 276$ m/ден) и со поситно зрнести разно гранулирани песоци со прослојки од глини со коефициент на филтрација $K = 1,73 \cdot 10^{-2} - 17,28$ m/ден. Над него се наоѓа покривен слој со значително послаби

филтрациони карактеристики, изграден од пескливи глини ($K = 2,16 \cdot 10^{-3}$ m/ден), и правливи песоци со коефициент на филтрација $K = 3,15 \cdot 10^{-2}$ m/ден.

Литолошко-хидрогеолошките карактеристики на покривните седименти не овозможуваат доволна заштита од загадување од површината на теренот на подземните води од алувионот на Брегалница во регионот на Делчево и затоа тие спаѓаат во групата води загорезени од загадување.